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ON THE ORIGIN OF HARD X RAY AND RADIO EMISSION DURING THE SOLAR FLARE OF 21 SEPTEMBER 1961

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SUMMARY

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The burst of X-rays during the flare of 21 September 1961 can be satisfactorily explained by bremmstrahlung of nonrelativistic electrons with $E_k \geqslant 20$ kev, with an exponential energy spectrum $\sim E_k^{-3}$. The lower limit of particle concentration in the emitting region is found to be equal to $\sim 10^{10}$ cm^{-3}. In order to explain the observed flux, N_e ($\geqslant 20$ kev) $= 3 \cdot 10^{35}$ electrons are required. If the spectrum of electrons is extended into the region of relativistic energies, the observed centimeter radioburst can be explained and the intensity of the magnetic field can be estimated and found to be equal to 160 oe. For the sake of comparison, an analogous computation is made for the flare of 20 March 1958.

Author

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The electromagnetic radiation is the most important source of information on processes taking place during solar flares, for, contrary to cosmic rays and corpuscular streams, this radiation is significantly less distorted over the path from Sun to Earth. At the present time the greatest number of experimental data on electromagnetic radiation with continuous spectrum are obtained for the radio and X-ray region of the spectrum. Particular interest is offered by the hypothesis on radio and

* O PROISKHOZHDENII ZHESTKOGO RENTGENOVSKOGO IZLUCHENIYA I RADIOIZLUCHENIYA PRI SOLNECHNOY VSPYSHKE 28 SENTYABRYA 1961 g.

X-ray burst generation by the same fast electrons, accelerated in the course of flare development.

The flare of 28 September offers in this regard the greatest interest, since a frequency spectrum in the region of $E_x \geqslant 20$ kev energies and the largest number of observation data on radio emission were obtained for it.

The active region, in which the flare took place, passed along the solar disk three times prior to it, and on 28 September its activity was already feeble. The optical emission in H_α began at 22 02 hours U.T. the flare had a force 3+, a substantial area ($980 \cdot 10^{-6}$ $S_\odot$), a high brightness (4) and a prolonged phase of growth (to 22 24 hours U.T.). At 22 11 hours began a brief increase in H_α brightness, coinciding with radioburst commencement, lasting to 22 13 hours, and interpreted in [1] as the beginning of charged particle acceleration. According to data obtained on Explorer-XII [2], cosmic rays with energies $\gg 100$ Mev were first registered at 22 39 hours UT. The energy spectrum of these particles was very hard at the beginning. More or less 2 hours after their arrival, protons with energies from 2 to 15 Mev were registered. After 02 29 hours UT of 29 September the spectrum of cosmic rays could be approximated by an exponential function with an exponent 2 — 3 (see, for example, [3]). The geomagnetic storm began 46 hours after the flare.

The experimental data on radio emission and X-ray burst are compiled in Table 1 [1, 4, 5]. From these data and from Figs. 8 and 9 of reference [4], it follows, that the temporal course of the radioburst, including the presence of the forerunner, corresponds very well to the temporal course of the X-ray burst. Such a coincidence is evidence that both forms of bursts are generated in the same region by electrons, accelerated during a certain time period during the process of flare development.

Assume, that the burst of X-rays arises as a result of bremmstrahlung emission of nonrelativistic electrons with energy $E_k \geqslant 20$ kev. For the differential cross section in this region of energies, we may take advantage of the following approximate expression [6, 7]:

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TABLE 1

Frequency mc/s	Commenc. Hrs UT	Maximum	Durat. min.	Flux in maximum $\frac{W}{m^2\,cps}\cdot 10^{22}$	$t^{-1/2}$	Forerunner
	RADIO EMISSION					
9400	22 13	22 17.3	40	1600	3	22 16
3750	22 12	22 17.3	40	1690		
2000	22 11	22 20.2	40	1000	5	22 15
1000	22 08		45	75		
900	22 13		90	900		
545	22 14		36	1000		
108	22 13	22 17	54	300		
18	22 14					
Type-II	22 17.5		14			
Type-III	22 16.5					
	22 17.3					
	22 18.7					
X-rays 20 kev	22 16	22 17	5	$7\cdot 10^{-6}$ erg cm^2 s	0,33	22 16
SEA 2	22 16	22 24	42			
S-SWFA 2	22 18		62			
	22 02	22 24	208			

[follows text from p. 2]

$$\frac{d\sigma}{d\nu} = \frac{8}{3} r_0^2 \alpha Z^2 \frac{mc^2}{E_k} \frac{1}{\nu} \ln \frac{\sqrt{E_k} + \sqrt{E_k - h\nu}}{\sqrt{E_k} - \sqrt{E_k - h\nu}} \times$$

$$\times \frac{1 - \exp\left(-\sqrt{2}\pi\alpha Z \sqrt{mc^2/E_k}\right)}{1 - \exp\left(-\sqrt{2}\pi\alpha Z \sqrt{mc^2/E_k - h\nu}\right)} \frac{\sqrt{E_k}}{\sqrt{E_k - h\nu}}, \qquad (1)$$

where $r_0 = e^2 / mc^2$; $\alpha = e^2 / \hbar c$; Z is the charge of the nucleus; ν is the frequency

It follows from (1) that the spectral power of electron bremmstrahlung with energy E_k is

$$p(\nu, E_k) = \frac{d\sigma}{d\nu} n_i v h\nu = A n_i Z^2 \sqrt{mc^2/h\nu}\, L(x, \nu), \qquad (2)$$

where

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where
$$L(x,\nu)=\frac{1}{\sqrt{x-1}}\ln\frac{\sqrt{x}+\sqrt{x-1}}{\sqrt{x}-\sqrt{x-1}}\,\frac{1-\exp(-b/\sqrt{x})}{1-\exp(-b/\sqrt{x-1})}\qquad(3)$$
$$x=E_k/h\nu,\quad A=(8\sqrt{2}/3)\,r_0^2\alpha hc\approx 4{,}30\cdot 10^{-43}$$
$$b(\nu)=\sqrt{2}\,\pi\alpha Z\sqrt{mc^2/h\nu}\approx 3{,}24\cdot 10^{-2}Z\sqrt{mc^2/h\nu};$$

ϑ is the electron velocity. For the exponential energy of electrons we have
$$dN_e(E_k)=\mathcal{K}E_k^{-\gamma}dE_k.\qquad(4)$$

From (2) we obtain
$$P(\nu)=\int_{h\nu}^{\infty}p(\nu,\,E_k)N_e(E_k)\,dE_k=A\sqrt{mc^2}\,\mathcal{K}n_iZ^2(h\nu)^{1/2-\gamma}I(\nu),\qquad(5)$$
$$I(\gamma,\nu)=\int^{\infty}L(x,\nu)x^{-\gamma}dx.\qquad(6)$$

The values of the functions L (x,ν) and I (ν) for various values of γ in (4) are compiled in the Table 2 hereafter.

TABLE 2

$h\nu$, кэв Kev / x	1,5	2	5	10	20	50	100	200
				$L\ (x,\nu)$				
1	0,8936	0,8026	0,5534	0,4094	0,2992	0,1958	0,1398	0,1002
2	1,3495	1,3364	1,3042	1,2876	1,2757	1,2651	1,2596	1,2558
3	1,3720	1,3658	1,3507	1,3429	1,3373	1,3323	1,3297	1,3279
4	1,3458	1,3421	1,3331	1,3284	1,3251	1,3222	1,3206	1,3196
5	1,3160	1,3081	1,3020	1,2989	1,2967	1,2947	1,2937	1,2930
6	1,2751	1,2733	1,2689	1,2666	1,2650	1,2636	1,2628	1,2623
7	1,2415	1,2406	1,2368	1,2351	1,2339	1,2328	1,2322	1,2318
8	1,2105	1,2094	1,2068	1,2054	1,2045	1,2036	1,2032	1,2029
9	1,1820	1,1811	1,1789	1,1779	1,1771	1,1764	1,1760	1,1758
10	1,1557	1,1550	1,1532	1,1523	1,1517	1,1511	1,1508	1,1506
12	1,1092	1,1086	1,1074	1,1067	1,1062	1,1058	1,1056	1,1055
14	1,0691	1,0687	1,0677	1,0672	1,0669	1,0666	1,0664	1,0663
16	1,0312	1,0338	1,0331	1,0327	1,0324	1,0322	1,0320	1,0319
18	1,0033	1,0030	1,0024	1,0021	1,0019	1,0017	1,0016	1,0015
20	0,9758	0,9756	0,9751	0,9748	0,9746	0,9744	0,9744	0,9743
30	0,8718	0,8717	0,8714	0,8713	0,8712	0,8711	0,8711	0,8711
40	0,8009	0,8009	0,8007	0,8006	0,8006	0,8005	0,8005	0,8005
50	0,7482	0,7481	0,7480	0,7480	0,7480	0,7479	0,7479	0,7479
				$I\ (\gamma,\nu)$				
$\gamma=2$	1,123	1,106	1,065	1,044	1,028	1,016	1,009	1,005
3	0,531	0,518	0,488	0,472	0,458	0,451	0,446	0,443
5	0,233	0,224	0,204	0,194	0,185	0,180	0,177	0,174
7	0,143	0,137	0,121	0,117	0,110	0,104	0,101	0,099

It may be seen from Table 2 that L and I are slowly-varying functions of ν ; that is why below they are considered as constant. Expressing $\mathcal{H}$ from (4) by a whole number of electrons N_e with energy $E_k \geqslant h\nu$ and integrating (5) over the frequency, we shall obtain a formula for the estimate of electron bremmstrahlung power, valid at $\gamma > 3/2$

$$P(E_x \geqslant h\nu) = 5{,}85 \cdot 10^{-20}\ f(\gamma) n_i N_e Z^2 \sqrt{h\nu}, \qquad (7)$$

where the function $f(\gamma) = (\gamma-1) I(\gamma) / (\gamma - 3/2)$ for $\gamma = 2;\ 2.5;\ 3.5,$ takes the values, respectively of 2.06; 0.975; 0.610; 0.211.

In order to obtain the observed flux of X-ray radiation at the Earth [4] $I(\geqslant 20\,\text{kev}) = 7 \cdot 10^{-6}$ erg/ cm^2 sec it is necessary that $I = P / 4\pi r_\odot^2 = 7 \cdot 10^{-6}$, , and hence

$$N_e(\geqslant 20\ \text{кэв}) = 1{,}9 \cdot 10^{45} / n_i f(\gamma), \qquad (8)$$

where n_i has the sense of mean concentration of particles in the whole volume of the emitting region.

The concentration n_i may be determined independently by utilizing the characteristic time of drop of X-ray burst intensity. From the data brought out in [4] for the flare of 28 September 1961, it follows, that upon reaching the maximum, the burst intensity dropped in 17 seconds by about a factor of 2 (from 22 17 hrs 3 sec to 22 17 hrs 20 sec.) This drop can be explained by electron egress from the emitting region, as well as by their energy losses. Let us consider the second possibility. From the Fig. 5 of ref. [4] it follows that the inclination of the spectrum of X-ray burst decreases with time. Such a decrease could be induced only by ionization losses, which drop with energy in the nonrelativistic region, as was correctly indicated in [4]. Here we should also add the argument, that the magnetobremmstrahlung losses of nonrelativistic electrons are neglectingly small in the condition of a solar flare, whereas the deceleration losses may be substantial only at a very high concentration of particles. Indeed, the deceleration losses in a plasma for nonrelativistic electrons are

$$-(dE_k / dt)_T = 1{,}15 \cdot 10^{-19} n_i Z^2 \sqrt{E_k}\ \text{erg/sec} \qquad (8\,a)$$

The mean time of electron energy decrease by a factor of 2 ("lifetime") is

$$\Delta t_T = 0{,}51 \cdot 10^{19} \sqrt{E_k} / n_i$$

Hence it follows, that for $E_h = 200$ kev, the value of $\Delta t_T = 17$ sec only at $n_i = 5 \cdot 10^{13} \text{cm}^{-3}$ (average by flare volume).

The ionization losses of electrons in a plasma is determined in the general case by the following expression [8] :

$$-(dE/dt)_u = \beta(E/\sqrt{E^2 - (mc^2)^2}), \qquad \beta = (2\pi e^4/mc) n_i Z L, \qquad (9)$$

where L is a multiplier, logarithmically dependent on energy and equal to ~ 25 in the nonrelativistic region and to 50 in the ultrarelativistic region of energies. The time of energy decrease from E_{k1} to E_{k2} from (9) is

$$\Delta t_u = \frac{1}{\beta} \left[\sqrt{E_k(E_k + 2mc^2)} - mc^2 \operatorname{arc\,tg} \frac{\sqrt{E_k(E_k + 2mc^2)}}{mc^2} \right]_{E_{k2}}^{E_{k1}}. \qquad (10)$$

From (10) we obtain for two boundary cases the expressions for the time of energy decrease by a factor of 2

$$\Delta t_{1/2} = 2{,}3 \cdot 10^3 E_k^{3/2} / n_i \quad \text{at} \quad E_k \ll mc^2, \qquad (11)$$

$$\Delta t_{1/2} = 1{,}3 \cdot 10^6 E_k / n_i \quad \text{at} \quad E_k \gg mc^2. \qquad (12)$$

Here and below, we took for the solar atmosphere Z = 1. In particular, from $E_k = 150$ kev and $\Delta t = 17$ sec., the value of $n_i = 7.8 \cdot 10^9 \text{ cm}^{-3}$, and for $E_k = 50$ kev, $n_i = 1.5 \cdot 10^9 \text{ cm}^{-3}$.

These values of concentration are the lower limit, since they are obtained in the assumption that the acceleration of particles during sharp drop of intensity is absent. In reality, at the end of this period (2217.03 sec.) a group of type-III radiobursts, excited, as is well known, by charged particles moving with a velocity $\gg 10^5$ km/sec, is observed. If these particles are electrons, their energy is $\gg 50$ kev. About the influence of acceleration during the period of intensity drop of the X-ray burst speaks also the fact, that the inclination of the spectrum varied little after two minutes of drop. On the other hand , the intensity drop may also be determined by the egress of fast electrons from the emission region, whose accounting will lead to the decrease of the possible value of n_i. (It should be noted, that if the time of X-ray burst intensity decrease by a factor 2 were determined only by ionization losses, one should have expected a notable change in the shape of the spectrum. Unfortunately, the determination of the spectrum by three points only does not permit to derive any somewhat reliable conclusions.). Thus, for the estimates concerning the flare of 28 September 1961, we may admit $n_i = 10^{10}\ \mathrm{cm}^{-3}$, and then, the total number of electrons from (8) is $N_e\ (\geqslant 20\,\mathrm{kev}) = 1.9 \cdot 10^{35} / f(\gamma)$. In particular, at $\gamma = 3$, we have $f(\gamma) = 0.61$ and $N_e = 3.1 \cdot 10^{35}$.

Let us consider now the question of radioburst generation. It follows from the Table 1 that the maximum in the frequency spectrum of the centimeter radioburst corresponds to the frequency $\nu_m = 4 \cdot 10^9$ cps. At synchrotron radiation, we have

$$\nu_c = 3{,}4\nu_m = 4{,}24 \cdot 10^6 H_\perp \varepsilon^2 \qquad (\varepsilon = E / mc^2), \tag{13}$$

and hence $H_\perp \varepsilon^2 = 3{,}2 \cdot 10^3$. The required energy of electrons is determined from the condition that the time of radioburst intensity drop by a factor of 2 at $\lambda = 3$ cm (~ 4 min., see Table 1) is determined by ionization losses. (The lifetime of electrons with energy $E = 2.3$ Mev is $4.5 \cdot 10^3$ sec. as a result of synchrotron losses in the field of 160 oe intensity; it is thus substantially greater than the lifetime of the radioburst). Utilizing (12) and with $n_i = 10^{10}\ \mathrm{cm}^{-3}$, we find

$$E_h = 1.83 \cdot 10^6\ \mathrm{ev} \ \ (E = 2.3 \cdot 10^6\ \mathrm{ev}) \quad \text{and} \quad H_1 \approx H = 160\ \mathrm{oe}.$$

Let us determine the total number of relativistic electrons with energy of 2.3 Mev, required for obtaining a radio emission flux in the frequency of $4 \cdot 10^9$ cps, equal to $1.7 \cdot 10^{-16}$ erg/cm^2. sec. cps, and observable on Earth. The spectral power of the synchrotron radiation is determined in the maximum only by the magnitude of the magnetic field and is [9]

$$p(\nu_m) = 1{,}6 e^3 H_\perp / mc^2 = 2{,}17 \cdot 10^{-22} H_\perp \ \mathrm{erg/sec \cdot cps} \tag{14}$$

From the condition $pN_e / 4\pi r_\delta^2 = 1{,}7 \cdot 10^{-16}$ at $H_\perp = H = 160$ we obtain $N_e = 1.4 \cdot 10^{31}$ electrons. On the other hand, as is shown above (see (8) at $n_i = 10^{10}\ \mathrm{cm}^{-3}$), in order to obtain the observed flux of X-rays,

N_e ($\geqslant 20$ kev) $= 1.9 \cdot 10^{35}/f(\gamma)$ electrons are required. Extending the exponential energy spectrum E_k^- in the region of relativistic energies, and assuming $\gamma = 3$ ($f(\gamma) = 0.612$), we obtain N_e ($E_k \geqslant 1.8 \cdot 10^6$ ev) $= 3.7 \cdot 10^{31}$ electrons, that is a value close to that found above from radioobservations.

Let us consider now other possibilities of explaining the observed burst of X-rays. At synchrotron nature of X-ray burst it is necessary that $h\nu_c = 20$ kev, whence, according to (13), $\varepsilon^2 = (E = (E/mc^2)^2 = 10^{12} / H_\perp$. In particular, at $H_\perp = H = 100$ oe, $\varepsilon = 10^5$ ($E = 5 \cdot 10^{10}$ ev). The lifetime of these electrons in a field 100 oe [8] is

$$t_{1/2} = 2.6 \cdot 10^{14} / H^2 E = 0.5 \text{ sec.}$$

Under such conditions, the time of intensity drop by a factor of 2 is determined by synchrotron losses and the spectrum of X-rays must become steeper, which does not agree with the observations of ref. [4]. Therefore, the synchrotron nature of the X-rays burst is little probable.

Let us consider with more detail the possibility of explaining the observed X-ray emission during the solar flare of 28 September as a result of Compton scattering of Sun's thermal photons on relativistic electrons (the so-called "inverse" Compton effect). At Compton scattering in conditions of solar atmosphere, the maximum in the energy spectrum of scattered γ- quanta fits the energy [8]

$$h\nu_k = \frac{4}{3} \bar{\varepsilon}_\Phi \left(\frac{E}{mc^2}\right)^2 = 1{,}83\varepsilon^2 \text{ ev} \qquad (\varepsilon_\Phi = 1{,}37 \text{ ev}), \tag{15}$$

and the total emission power per electron is

$$p = 2{,}67 \cdot 10^{-14} \bar{n}_\Phi \bar{\varepsilon}_\Phi (E / mc^2)^2 = 5{,}4 \cdot 10^{-14} \varepsilon^2 \text{ erg/sec} \tag{16}$$

where n is the mean concentration of thermal photons, about equal to $0.92 \cdot 10^{12}$ cm^{-3} for the solar atmosphere. From the condition $h\nu_k = 1{,}83\varepsilon^2 = 2 \cdot 10^4$ we find

$$\varepsilon^2 = 1{,}1 \cdot 10^4 \qquad (E = 5{,}5 \cdot 10^7 \text{ ev}).$$

According to (16), the emission power $p = 5.9 \cdot 10^{-10}$ erg/sec.

The observed flux at the Earth is $pN_e/4\pi r_{\odot}^2 = 7\cdot10^{-6}$ erg/cm^2, and hence the required number of electrons is $N_e = 3.3\cdot10^{31}$. But could these very same electrons induce the observed radioburst as a result of their synchrotron radiation ? The radioburst maximum from observations (Table 1) fits the frequency $\nu_m = 4\cdot10^9$ cps ($\nu_c = 1.4\cdot10^{10}$ cps). From the condition $4.24\cdot10^6 H_\perp \varepsilon^2 = 1.4\cdot10^{10}$ (see (13)), we find $H_\perp = H = 0.3$ oe. According to (14) the power in the maximum is $p(\nu_m) = 6.5\cdot10^{23}$ erg/sec cps and the flux at the Earth is $I \approx 7.6\cdot10^{-19}$ erg/cm^2 sec cps, which is 220 times less than the observed flux. Such a small value of the flux is the consequence of too low an intensity of the magnetic field in the emitting region, which in its turn follows from the presence of the maximum in the frequency spectrum of the radioburst in the frequency of $4\cdot10^9$ cps. If we now make the little probable assumption, that the maximum in this frequency is an error of the experiment and that, in reality, it should fit greater frequencies, the intensity of the magnetic field may be determined from the condition that the radio emission flux in the frequency of 10^{10} cps be equal to the observed value of $1.6\cdot10^{-16}$ erg/cm^2 sec cps.

For the estimate, we shall take advantage of the following formula for the spectral power of synchrotron emission [8, 9] :

$$p(\nu) = \sqrt{3}\,\frac{e^3 H_\perp}{mc^2} F(y) \approx 2{,}36\cdot10^{-22} H_\perp F(y), \qquad (17)$$

where

$$F(y) = y \int\limits_y^\infty K_{5/3}(x)\,dx = \begin{cases} 2{,}16 y^{1/3} & \text{at} \quad y = \dfrac{\nu}{\nu_c} \ll 1 \\ 1{,}25 y^{1/2} e^{-y} & \text{at} \quad y \gg 1. \end{cases} \qquad (18)$$

In the particular case $\nu = \nu_m$, $F(y) = 0.912$, we shall precisely obtain the expression (14) from (17).

From the condition $pN_e/4\pi r_{\odot}^2 = 1{,}6\cdot10^{-16}$, we find $H_\perp F(y) = 0{,}58\cdot10^2$. But at $\nu \ll \nu_c$, according to (18), $F(y) = 2{,}16(\nu/\nu_c)^{1/3} = 1{,}3 H_\perp^{-1/3}$ (see (13), at $\varepsilon = 1.1\cdot10^4$), and that is why $H_\perp \approx H = 300$ oe. For such a field and an energy of $5.5\cdot10^7$ ev, $\nu_c = 1.4\cdot10^{13}$ cps and the maximum flux is equal to about 10^{-15} erg/cm$^2\cdot$sec$\cdot$cps.

Therefore, if the observed burst of X-rays during the flare of 28 September has a Compton nature, it requires $3.3 \cdot 10^{31}$ electrons with energy of $5.5 \cdot 10^{7}$ ev. The same electrons could have induced the observed centimeter radioburst only in the case when the magnetic field in the emission region is $H \approx 300$ oe; at the same time, the maximum in the frequency spectrum, contrary to observations, would fit the frequencies of $\sim 10^{13}$ cps, while the flux in the maximum would be $\sim 10^{-15}$ erg/cm^2·sec·cps.

Another objection to the assumption made is linked with the duration of the burst of X-rays and of the radioburst. The time of rapid decrease in intensity of X-ray burst by a factor of 2, Δt_X, is near 17 sec., as pointed out above, while the corresponding time for the radioburst in the 3.15 cm wavelength, Δt_p, is ~ 3 min. If the burst of X-rays and the radioburst were generated by the same electrons, one should have expected that $\Delta t_X = \Delta t_p$. The existing discrepancy can be explained, if one assumes, as was done above, that different portions of energy spectrum of electrons are responsible for the radioburst and burst of X-rays. However, even for synchrotron losses, which depend most of all on energies ($\sim E^2$), the "lifetime" is proportional to $1/E$ and for the observed discrepancy by order between Δt_X and Δt_p it is necessary to prolong the energy spectrum of electrons to energy of of $5 \cdot 10^{6}$ ev. At the same time serious difficulties arise when explaining the other observed characteristics of X-ray and radio bursts.

Therefore, the above-developed notion of decelerating nature of X-rays agrees better with the available experimental data. This assumption allows the explanation of other peculiarities of radiobursts also. For the above-found concentration of particles in the emitting region, $n_i = 7.8 \cdot 10^{9}$ cm^{-3} and magnetic field intensity of 160 oe, the plasma frequency is $\nu_p = 8 \cdot 10^{8}$ cps, and the cyclotron frequency $\nu_H = 4.3 \cdot 10^{8}$ cps. Thus radio emission in the frequency of 10^{9} cps will be significantly weakened by absorption, which explains the character of the centimeter radioburst, while the radiation in the frequencies $\leqslant 8 \cdot 10^{8}$ cps could not emerge from this region. The nearly simultaneous commencement of the meter radioburst encompassing a large frequency band from 18 mc/s, means that the perturbation during flare spread for a short time to heights of $\sim 500\,000$ km (level of output for 18 cps). This is naturally explained by a break-through of fast electrons from the acceleration region to the corona, where, as a result of synchrotron emission, they generate a meter radioburst.

A rough estimate of the magnetic field in this region may, within the framework of the above-developed model, be made as follows. From observations, the maximum of meter radioburst fits the frequency of $4 \cdot 10^8$ cps, that is a frequency about 10 times lower than for the centimeter radioburst, while the flux in the same frequency is about the same as in the its maximum ($\sim 1.6 \cdot 10^{-16}$ erg/cm$^2 \cdot$ sec $\cdot$ cps). That is why, the magnetic field in the region of the meter radioburst for the same energy of electrons must be, according to (13), 10 times weaker, that is, equal to 16 oe, while the total number of electrons, according to (14), is 10 times greater than for the centimeter radioburst ($1.4 \cdot 10^{32}$). This means, that the overwhelming part of accelerated electrons emerged into the upper atmosphere of the Sun. If, however, we take into account, that for the above-found spectrum of electrons, E_k^{-3}, a significant contribution will be made to the meter emission by electrons with energies $E_m \leqslant 2.3 \cdot 10^6$ ev, whose radiation in the centimeter radioburst region is absorbed, we shall have at $E_m = 10^6$ ev, $H \gtrsim 60$ oe and about half of all the accelerated electrons emerge from the acceleration region into the corona.

The systematic lag in the commencement of centimeter radioburst with frequency can be explained by the fact, that acceleration of electrons began in the region of a weaker magnetic field and lower concentration of particles, for example above the region of H_α glow, and then spread downward, into the denser region with stronger magnetic field.

In conclusion we shall bring forth, for the sake of comparison, an analogous calculation for the flare of 20 March 1958. Assume that the radioburst arises during that flare as a result of synchrotron radiation of relativistic electrons with the same energy $E = 2.3$ Mev. If the drop in radioburst intensity by a factor of 2 (30 sec. according to [10]) takes place because of ionization losses of electrons, it results from (12) that $n_i = 7.7 \quad 10^{10}$ cm^{-3}. In order to have the maximum in the frequency spectrum fit a frequency $\nu_m \gg 10^{10}$ cps at electron energy of 2.3 Mev, it is necessary (see (13)), that $H \gg 340$ oe. Let us adopt the lower value for the estimates. Then $2.7 \cdot 10^{30}$ electrons with energy of 2.3 Mev will be required for the observed radio emission flux in the maximum, equal to [5] $7.2 \cdot 10^{-20}$ w/m$^2 \cdot$cps.

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Assume now, that the burst of X-rays during the flare of 20 March 1958, just as in that of 28 September 1961 arises as a result of bremmstrahlung of fast electrons with energy $\geqslant$ 200 kev*). When making the estimates, we shall utilize for simplicity, the formula (8a) for total deceleration losses. In order to obtain the observed flux [10] $I = 1.6 \cdot 10^{-5}$ erg/cm^2 sec at the above-found concentration $n_i = 7.7 \cdot 10^{10}$ cm^{-3}, it is necessary to have $5.85 \cdot 10^{33}$ electrons. This value may be coordinated with the one found from radioobservations, provided one assumes, that the energy spectrum of electrons is exponential with an exponent $\gamma = 4$ in the differential spectrum. In reality this value of γ should be substantially decreased, for, at concentration of $7.7 \cdot 10^{10}$ cm^{-3} ($\nu_p = 2.5 \cdot 10^9$ cps) and a field $H = 340$ oe ($\nu_H = 10^9$ cps) radio emission in the frequencies $\leqslant 10^{10}$ cps will be substantially weakened by absorption, while on frequencies $< 2.5 \cdot 10^9$ c.p.s. it can emerge only from the outer parts of the emitting region, where the concentration of particles is likely to be substantially lower.

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**** THE END ****

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*) It was shown in reference [11], that the burst of X-rays of 20 March may be explained by the inverse Compton effect. However, at bremmstrahlung estimates it is assumed that $n_i = 4 \cdot 18^8$ cm^{-3} (which is the normal concentration in the corona at 20 000 km height). If we take a value by two orders greater, quite possible in the region of H_α emergence or above it, bremmstrahlung will significantly exceed the Compton emission.